package (i.e., to keep the concentration gradient high) are unlikely, requiring liquid water to drip onto cracks or holes in the waste package. Calculations of diffusion under any likely condition show that releases by this mechanism are unlikely to cause doses anywhere approaching the dose limits, even under the failure or underperformance of other barriers.

Uncertainties

Mechanisms whereby the rock is forced into close contact with the waste packages may enhance diffusion by lowering the external resistance. Such processes may include engineered backfill, infilling of drifts by collapse, and igneous intrusion.

Degradation of the waste package that results in large openings and short diffusion pathways inside the waste package would reduce internal resistance to diffusion.

Effect of Colloids on Waste Package Releases: Medium Significance to Waste Isolation

Colloids can form from the aqueous degradation of fuel and especially vitrified waste. For the degradation of fuel, dissolved radionuclides, in addition to colloids directly resulting from waste-form degradation, can attach to natural or anthropogenic (human-caused) colloids, especially iron oxyhydroxides formed from corrosion of the steel in the waste package and ground-support materials. Degradation of glass in vitrified waste can form clay colloids such as smectite and illite, which can also be the substrate for radionuclide attachment. Colloids can be transported out of the waste package primarily by advection in flowing water. However, colloids may be easily filtered once in a porous medium such as the invert, the Calico Hills vitric unit, and the alluvium.

Discussion

Colloids may be important to repository performance if sufficient experimental evidence indicates they will form in large amounts and not be removed in substantially the subsurface through coagulation and filtration. Figure 4-21 shows the results of a bounding approximation of colloid effects by eliminating all retardation of plutonium, americium, and thorium isotopes. These results led to significant increases in dose, although still below the 0.15-mSv/yr [15-mrem/yr] regulatory criterion (Contardi, et al., 1999; Mohanty, et al., 2003). However, these results were highly conservative because they assumed that all releases from the waste form would leave the waste package and not be removed by filtration or straining. Experimental results on plutonium and americium releases from spent nuclear fuel suggest that colloidal radionuclides easily become attached to surfaces such as the interior of the waste package, and may not be released easily (Wilson, 1989).

DOE has performed analyses to evaluate the sensitivity of colloids where plutonium and americium are irreversibly sorbed to waste-form colloids (Figure 4-22). The DOE analyses

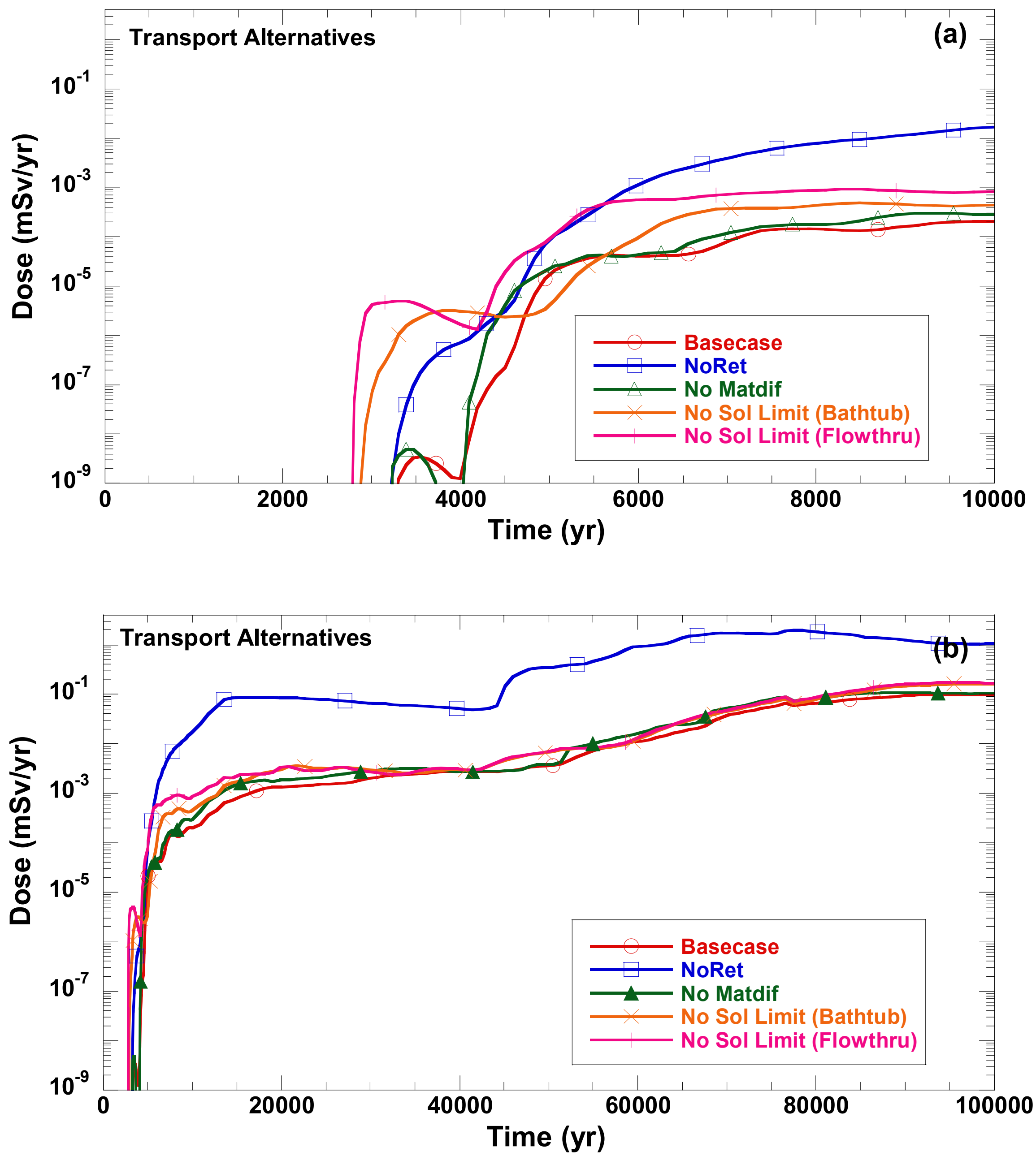
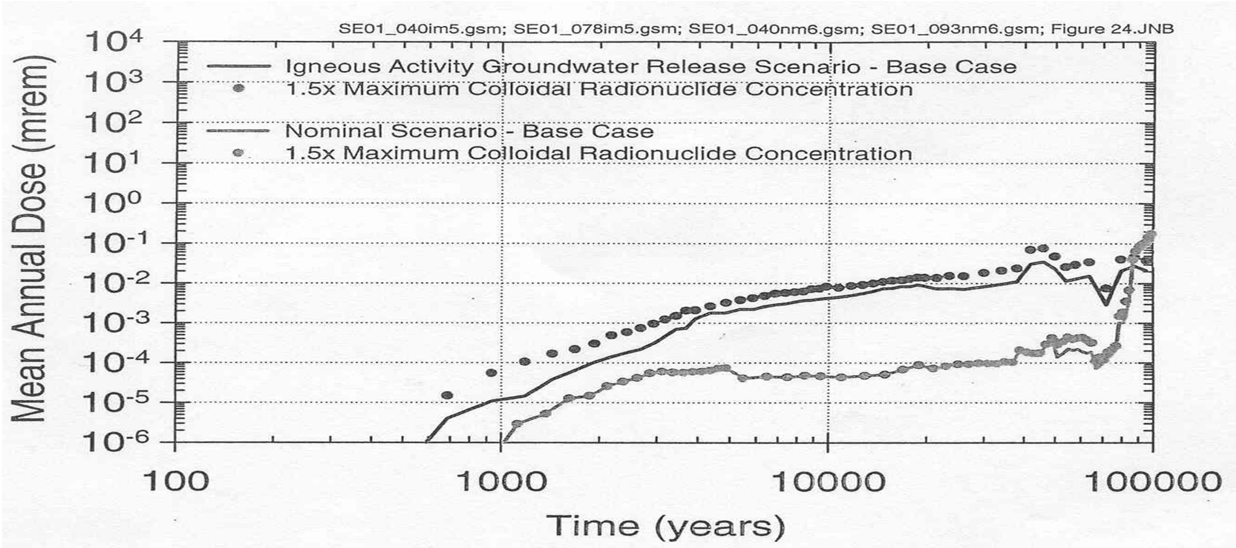


Figure 4-21. Dose Curves for Alternative Transport Models in TPA Version 4.1 Code Basecase Model (Basecase); Assumption of No Retardation (NoRet); Assumption of No Matrix Diffusion (No Matdif); and Assumption of No Solubility Limits (no Sol Limit) with the Bathtub and Flow-Through Models. The NoRet Curve Provides a Conservative Upper Bound to Colloidal Effects Simply by Assuming No Retardation of Plutonium, Americium, and Thorium Isotopes. The NoRet Case Yields Doses about One Order of Magnitude Higher than the Basecase, Which Is Less Than 10^{-3} mSv/yr [10^{-1} mrem/yr] (Mohanty, et al., 2002, Figure 3-38).



NOTE: Each mean annual dose curve is a probability-weighted average. However, the results of the sensitivity studies do not correspond to expected risk (see introduction to Section 3).

Figure 4-22. Sensitivity of Mean Annual Dose to Concentration of Plutonium and Americium Irreversibly Sorbed to Waste Form Colloids (Bechtel SAIC Company, LLC, 2002, Figure 24. Note that Dose Estimates for Variations from the Basecase Do Not Represent Variations in Expected Risk because the Probability of the Variation Is Not Considered) (1 mrem = 0.01 mSv)

indicated that colloidal concentrations were only significant in 10,000 years, under an intrusive igneous event, wherein a large number of waste packages are significantly damaged. The potential importance of colloidal transport, if all waste packages were to fail within 10,000 years, is evident in the DOE Total System Performance Assessment—Site Recommendation (CRWMS M&O, 2000b), which indicated colloidal plutonium is the second highest dose contributor after 70,000 years, when a significant number of waste packages are estimated to have failed, allowing release of radionuclides.

Uncertainties

Some measurements in the field indicate that colloids can travel relatively easily in the ground under the right conditions (Kersting, et al., 1999). However, release and transport parameters for colloid effects for the proposed repository are not supported by extensive field and laboratory data and near-field effects are not well-constrained.

Invert Flow and Transport: Low Significance to Waste Isolation

The invert has a short travel pathway relative to the geologic barriers and is not expected to have a significant effect on radionuclide transport in the aqueous phase.

Discussion

Although the invert is likely to consist of a porous or crushed rock material and have desirable properties for radionuclide sorption and possibly colloid filtration, it is very thin compared to other porous materials in the pathway of radionuclide transport, such as the Calico Hills vitric unit and alluvium. Performance assessment studies showed practically no effect of eliminating the invert as a barrier (Mohanty, et al., 2002).

Uncertainties

Any benefit of the invert may be lost over time if precipitation of minerals from ground water or alteration of minerals in the material by heat cause the porosity to decrease, thereby allowing short-circuiting around the porous material.

Criticality: Low Significance to Waste Isolation

The potential for criticality to occur either within the waste package or in the geosphere is considered unlikely; in addition, if it were to occur, the consequences would be limited (e.g., at most doubling of the inventory of fission products and locally increasing the temperature).

Discussion

Commercial spent nuclear fuel that would be stored in the potential repository cannot become critical unless there is sufficient water or other neutron moderator material in the waste package, and criticality controls (e.g., poisons) are removed or rendered ineffective. Neither the drip shield nor the waste package are expected to fail within 10,000 years. Furthermore, their failure is not expected to result in water sufficiently filling the waste package to submerge fuel elements. Criticality is also limited by the presence of nuclear poisons such as the borated stainless steel fuel baskets and the actinides and fission products within spent nuclear fuel. The boron in the stainless steel may eventually leach out, depending on the corrosion rate of the material and the rate of water circulation through the waste package to carry it away.

Should a criticality eventually occur, the event has been postulated to be either steady-state or transient in nature. In the steady-state case, power from the nuclear chain reaction could be limited by the availability of the water moderator, which would be controlled by the balance of heat generation and removal of heat by conduction and evaporation. The consequences of this situation would be modest, leading to elevated temperature of the waste package, and the generation of additional radioactive inventory in the spent nuclear fuel (Figure 4-23). However, steady-state criticality events may extend for thousands of years at low power levels provided that the waste package remains filled with water. Transient criticality could occur if there were rapid reactivity insertion caused by, for example, the sudden rearrangement of fuel and the water moderator from seismic shaking of partially failed waste packages, or seismically induced sloshing providing more moderation to the less-burned ends of the fuel rods. A transient criticality could potentially disrupt the waste form, cladding, and the waste package through a steam explosion (Figure 4-24).

Criticality outside of the waste package is not expected because there are no likely mechanisms that could reasonably reconcentrate the released fissile materials into a critical configuration.

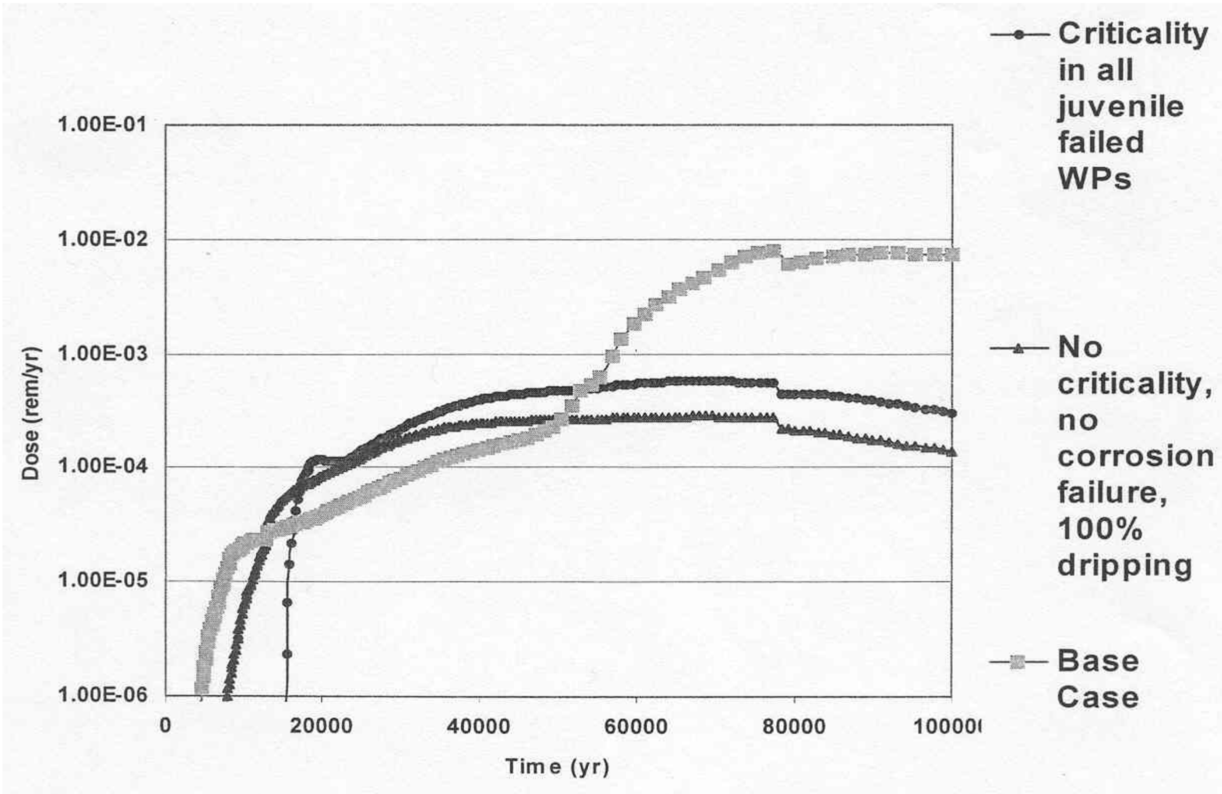


Figure 4-23. Dose Consequence of In-Package Steady-State Criticality (Waste Packages) (Mohanty, et al., 2002, Figure G-2) (1.0 rem/yr = 0.01 Sv/yr)

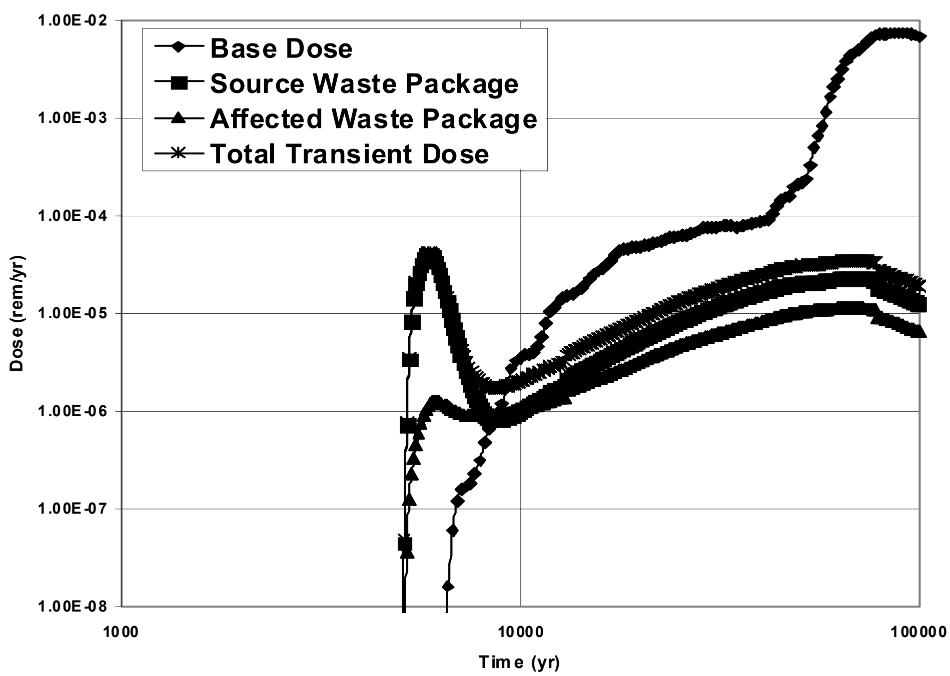


Figure 4-24. Dose Consequence of In-Package Transient Criticality (Mohanty, et al., 2002, Figure G-3) (1.0 rem/yr = 0.01 Sv/yr)

Uncertainties

The identification of scenarios resulting in a significant number (greater than 40) of simultaneously long-lived critical waste packages or transient criticality would merit further refinement of the consequence evaluation only if they could be shown to be likely to occur.

4.3.5 Climate and Infiltration (UZ1)

Risk Insights:	
Present-day Net Infiltration Rate	Medium Significance
Long-term Climatic Change	Medium Significance

4.3.5.1 Discussion of the Risk Insights

Present-day Net Infiltration Rate: Medium Significance to Waste Isolation

Estimates of present-day net infiltration rates are important for estimating the deep percolation rate. The deep percolation rate, in turn, affects the quantity of water coming into contact with the waste packages and waste form.

Discussion

Some of the precipitation that falls on Yucca Mountain is expected to move into the bedrock as net infiltration. Estimates of present-day net infiltration rates are used to directly estimate deep percolation rate at the repository horizon, assuming no lateral diversion of flow. Some fraction of this deep percolation is expected to seep into the repository drifts and come into contact with the waste packages, and, potentially, the waste form. Water coming into contact with waste packages will likely affect the integrity of the waste packages and the release of radionuclides from the waste form. The quantity of water has a more significant effect on the rate of release of radionuclides that have lower solubility limits. Of these radionuclides, Np-237 has the greatest potential to contribute to dose during the period of regulatory interest. Deep percolation rate and, thus, net infiltration, also directly affects the transport of radionuclides from the repository horizon to the saturated zone.

Net infiltration is directly related to climatic and surface conditions. Precipitation occurs episodically at Yucca Mountain, with years between rain events that lead to infiltration below the surface. Near-surface processes such as evaporation, plant transpiration, and overland runoff reduce net infiltration to approximately 5 percent of total precipitation on an annual average basis (Figure 4-25). Net infiltration estimates are the highest along the Yucca Mountain crest and the eastward trending ridge tops, because of the incidence of thin soils, precipitation increasing as a function of elevation, intermediate permeability of the caprock units, and high permeability of the open and soil-filled fractures. Surface water runs off toward channels and the toes of steep slopes and can increase net infiltration at these locations, though these locations tend to have relatively small surface areas.

Thin soil layers allow infiltration to enter fractures in the underlying bedrock more quickly and, thus, escape loss through evaporation. Simulations of bare soil infiltration indicate that mean

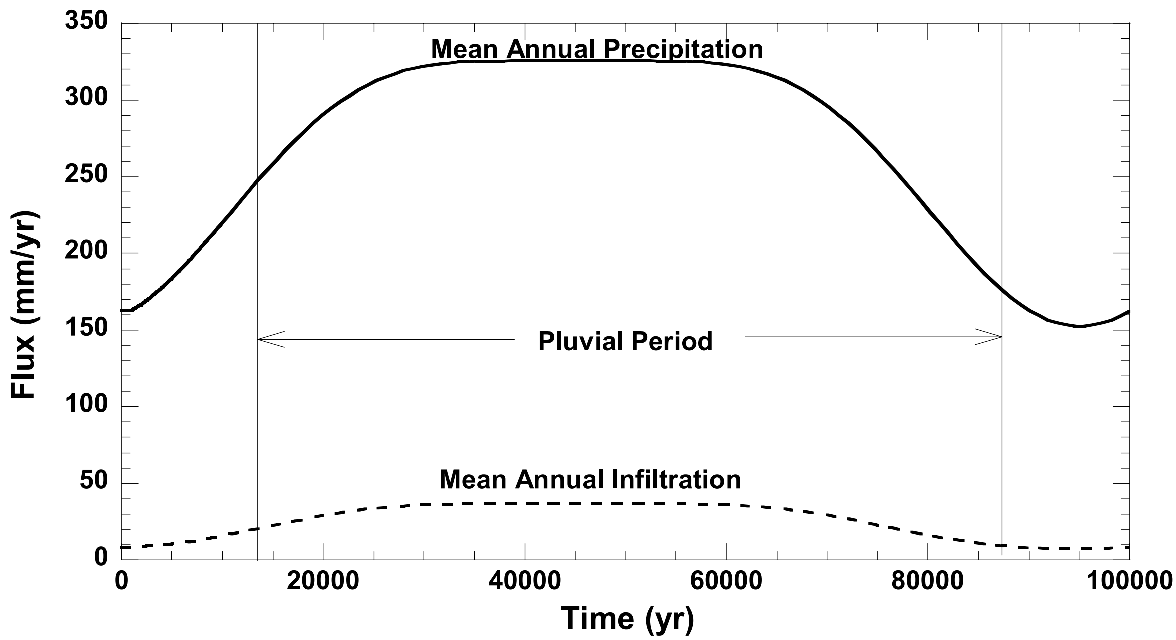


Figure 4-25. Mean Annual Precipitation and Infiltration at the Repository Horizon Averaged Over All Subareas and Encompassing Both the Current and Pluvial Periods for the Mean Value Data Set (Mohanty, et al., 2002, Figure 3-1)

annual infiltration is strongly dependent on surface soil thickness (Stothoff, et al., 1997; Stothoff, 1999). Mean annual infiltration estimates are generally higher for areas where soil thickness is 0.5 m [20 in]. Whereas exposed bedrock promotes runoff, the high permeability of soils allows for storage of water from intense rain events. Once the water capacity of thin soils is filled, open and soil-filled fractures in the bedrock readily transmit water to sufficient depth beyond the reach of transpiring plant roots, thus becoming net infiltration.

At Yucca Mountain, most of the repository footprint is overlain by thin soil layers less than 0.5 m [20 in] thick, with significant variability across the site. Both the DOE and NRC soil depth models qualitatively represent the system, in their respective performance assessment models, with consideration of the significant variability across the site.

The spatial variation in precipitation, soil thickness, and bedrock properties over the repository footprint have been explicitly incorporated into the calculation of mean annual infiltration, and thus deep percolation, for each subarea of the repository.

Using TPA Version 4.1 code in sensitivity analyses, Mohanty, et al. (2002) determined that the mean areal average infiltration into the subsurface was one of the two most influential parameters corresponding to overall peak risk (Table 4-5). The peak dose estimates from each realization were also found to be most sensitive to the mean areal average infiltration into the subsurface (Figure 4-26). In addition, the subarea wetted fraction, which is correlated to mean annual net infiltration, was also found to be an influential parameter (Table 4-5 and Figure 4-26).

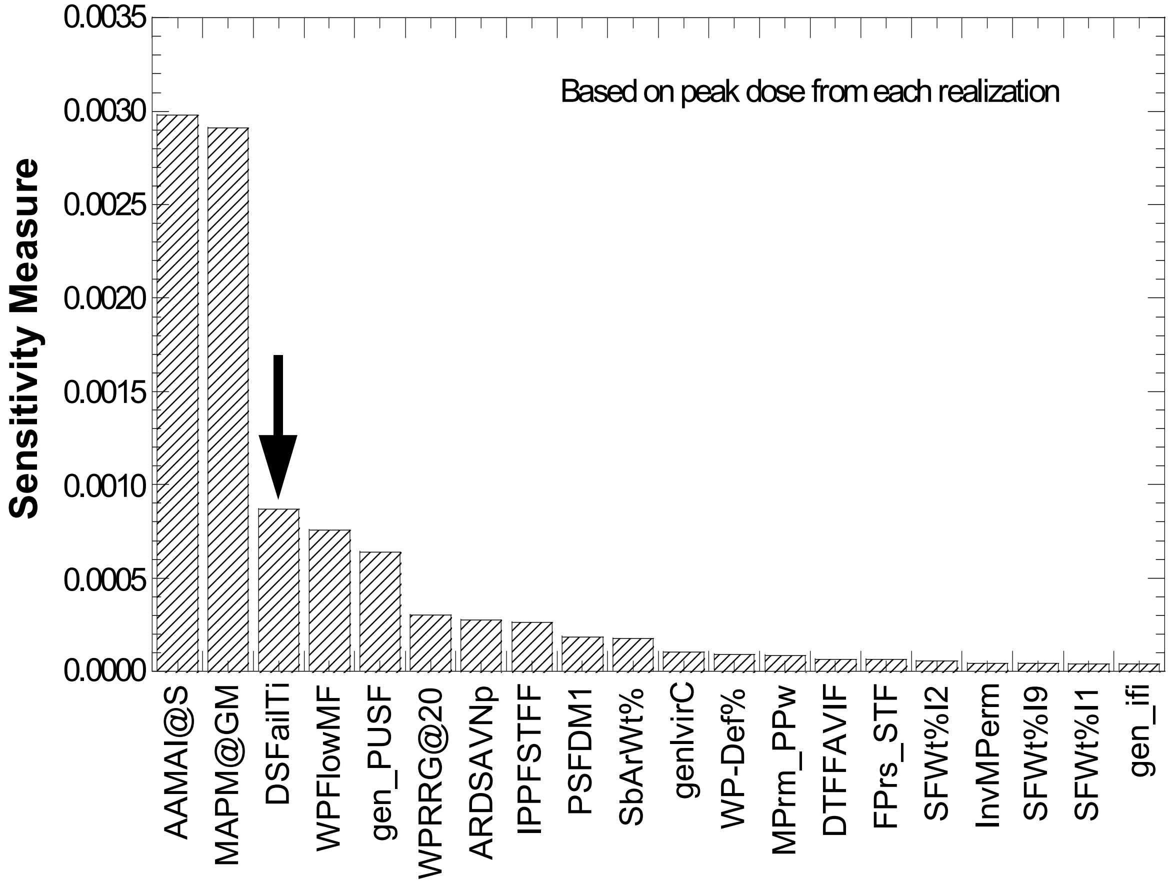


Figure 4-26. Influential Parameters Identified Using the Peak Dose from Each Realization (Mohanty, et al., 2002, Figure 4-6)

Uncertainties

Estimates of uncertainty for net infiltration are mostly based on modeling analyses that take into consideration the uncertainty in individual model parameters. The average net infiltration rate for the repository footprint area is estimated, in the TPA Version 4.1 code, to range from 4 to 13 mm/yr [0.2 to 0.5 in/yr] for the modern climate. The DOE performance assessments probabilistically consider a set of low-, medium-, and high-infiltration scenarios, which, for the modern climate conditions, spans a similar range of area-averaged infiltration rates. Reducing the uncertainties in net-infiltration estimates remains difficult because it is not possible to accurately measure net infiltration in environments where thin soils overlay bedrock. It is also difficult to estimate appropriate representative values for bulk bedrock permeability and soil thickness, which are important input parameters for net-infiltration models. Nevertheless, confidence in the current range of uncertainty estimated for net-infiltration rates is gained through other lines of evidence, such as analysis of temperature data and chloride content in perched water and in rock matrix.

A representative soil thickness is not easily supported by measurements because of the high degree of natural variability over small spatial scales. However, because most of the potential repository footprint at Yucca Mountain is estimated to be overlain by soil layers less than 0.5 m (20 in) thick, and is correspondingly represented in the DOE and NRC soil depth models, the uncertainty in the soil cover thickness would not likely lead to overly optimistic estimates of repository performance.

Long-Term Climatic Change: Medium Significance to Waste Isolation

Long-term climatic change, in terms of changes in precipitation and temperature, will directly affect the rate of net infiltration and, subsequently, deep percolation rate.

Discussion

One of the main processes that control net infiltration is climatic conditions, expressed in terms of temporal and spatial variation of precipitation and temperature. Annual net infiltration is expected to vary over the long term (i.e., thousands of years) because of variation in temperature and precipitation. Based on historical data and paleoclimatic markers, a full cycle of climatic changes is assumed to occur roughly every 100,000 years. Monsoonal conditions (wetter and hotter than present) and glacial transition conditions (wetter and cooler) may occur within the next 10,000 years.

In the NRC analyses (e.g., the TPA Version 4.1 code basecase scenario), the full glacial climate is assumed not to occur during the 10,000-year performance period. Figure 4-27 shows the mean net infiltration rates across all subareas is expected to increase from 8 mm/yr (0.3 in/yr) for the present-day climate to 15 mm/yr [0.6 in/yr] during the 10,000-year period of regulatory interest (i.e., a partial transition to a glacial climate), which is less than a factor of two increase. During a full glacial period starting at 30,000 years, the net infiltration rate is expected to range between a minimum of 4 mm/yr [0.2 in/yr] to a maximum of 30 mm/yr [1.2 in/yr].

In particular, the DOE performance assessment approach assumes an early and instantaneous transition to a monsoonal climate in an average time of 600 years from present and another instantaneous change to a glacial transition climate in about 2,000 years from present. These climate changes have a significant effect on net infiltration estimates. For example, in the DOE medium-infiltration case, the area-averaged net infiltration over the unsaturated zone model domain is increased from 4.6 to 12.2 mm/yr [0.2 to 0.5 in/yr] after the change to a monsoonal climate, and subsequently increases to 17.8 mm/yr [0.7 in/yr] for the glacial transition climate. Thus, the DOE performance assessment approach considers approximately a factor of four increase in net infiltration (for the medium-infiltration case) as a result of climate change during the performance period. As previously discussed in this section, this increased net infiltration significantly affects both drift seepage rates and the rate of radionuclide transport in the unsaturated zone.

Uncertainties

Important uncertainties pertaining to climate change are the timing of the onset of climate change, and the magnitude of temperature and precipitation changes that may occur as a result of the climate changes. NRC and DOE use different approaches to estimate future climatic conditions. NRC uses a smooth transition from the modern climate to a glacial-transition climate, combined with random sampling of a precipitation multiplier and a temperature shift. DOE uses an instantaneous step-function approach, combined with upper-bound, mean,

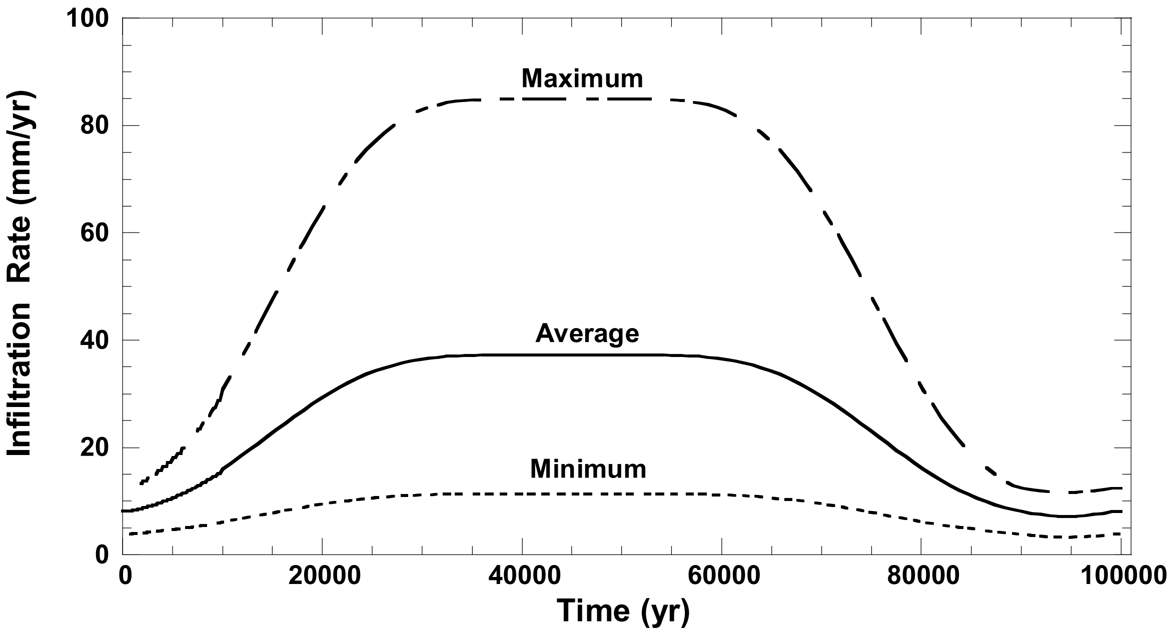


Figure 4-27. Mean, Maximum, and Minimum Infiltration Rates in the Unsaturated Zone for All Subareas (The Subarea Average Infiltration Rate Is Obtained by Averaging Over All 350 Realizations.) (Mohanty, et al., 2002, Figure 3-21)

and lower-bound precipitation and temperature records, which results in higher estimates of net infiltration rates over the 10,000-year performance period. The DOE step-function approach is based on recent evidence presented in the scientific community supporting much faster climate transitions than previously believed likely to occur. The DOE upper-bound, mean, and lower-bound precipitation and temperature records are based on measurements obtained from a range of analog sites that are believed to adequately bound the likely magnitude of climate changes that might occur at Yucca Mountain.

Neither NRC nor DOE approaches consider the potential effects of anthropogenically induced global warming. In general, the exclusion of anthropogenic effects on climate is believed to be conservative because global warming would increase temperature and reduce precipitation in the Yucca Mountain region.

Another model uncertainty is that periods of climate transition may lead to increased net infiltration as vegetation and soil thickness (e.g., erosion) do not immediately adjust to the new climate conditions; however, climate-induced changes in vegetation and soil cover would be relatively short-lived compared to the 10,000-year performance period, and thus this uncertainty is believed to be relatively unimportant.

4.3.6 Flow Paths in the Unsaturated Zone (UZ2)

Risk Insights:	
Seepage	High Significance
Hydrologic Properties of the Unsaturated Zone	Medium Significance
Transient Percolation	Low Significance

4.3.6.1 Discussion of the Risk Insights

Seepage: High Significance to Waste Isolation

Seepage of water into the drifts determines the amount of water that comes into contact with the drip shields and waste packages and affects the release and transport of lower-solubility radionuclides (e.g., Np-237). The amount of seepage is expected to affect the formation of salts on the surfaces of the drip shield and waste packages.

Discussion

Seepage is important for estimating releases from the repository because: (i) the amount of seepage affects the release of radionuclides that have low solubility limits, (ii) the spatial variability in seepage affects the number of waste packages that are estimated to be dripped on, and (iii) the amount of seepage affects the formation of salts on the surfaces of the drip shield and waste package. In part, because of the technical difficulties in determining the location and extent of dripping, performance assessments have generally assumed that dripping will occur in a significant portion of the repository (e.g., on the order of 25 percent) and a portion of this dripping water will enter breached waste packages.

Releases are estimated to be greatest where dripping water (seepage) enters a waste package and radionuclides are transported by the water out of the package. Thus, the spatial variability of seepage will affect releases by affecting the number of waste packages that are dripped on. If only a small number of waste packages experience dripping, the estimates of dose would be expected to diminish accordingly.

Seepage is expected to be the primary mechanism for transporting radionuclides out of the waste package. The amount of dripping water is not expected to significantly affect radionuclides with high solubility limits (e.g., I-129 and Tc-99) because estimates indicate only a small amount of water is needed to mobilize these radionuclides. However, solubility-limited radionuclides (e.g., Np-237 and Am-241), which comprise the bulk of the radionuclide inventory, can be affected by the amount of seepage (Table 4-6). Estimates indicate these radionuclides are generally slowed or retarded during transport in the geosphere during the first 10,000 years.

Seepage also affects the rate of corrosion of the drip shield and waste package. The formation of aggressive salts due to evaporation of seepage on the waste package may result in accelerated corrosion. These issues are discussed in greater detail in Sections 4.3.1 and 4.3.3.

Table 4-6. Water Flow into Waste Package Water Influx Sensitivity				
	WP Breach at 5,0000 Years		**WP Breach at 1,000 Years**	
Nuclide	**Low Flow**	**High Flow**	**Low Flow**	**High Flow**
Tc-99	>7,000	>7,000	>7,000	3,100
I-129	>7,000	>7,000	>7,000	6,700
NP-237	>7,000	120	>7,000	40
Am-241	>7,000	65	>7,000	1
Pu-240	>7,000	2	>7,000	1
*Packages Needed to Release {15 mrem/year [0.15 mSv/year]} at Drift Wall—No Geologic Delay				

Uncertainties

Quantitative assessments of potential seepage of water into repository drifts and onto waste packages are complicated by factors such as heterogeneity in the unsaturated zone, thermal perturbations to the flow field, capillary processes in fracture networks intersecting large openings, drift degradation, and thermal effects. Current approaches estimate the location and amount of dripping based on a variety of information (e.g., mining experience, numerical modeling, and field experiments) to provide a range for expected behavior. It is difficult to accurately quantify the effect of the waste heat on the unsaturated flow field. However, the uncertainties cannot increase dripping by more than a factor of four, at most, because performance assessments have generally assumed dripping will occur in a significant portion of the repository (e.g., on the order of 25 percent). The waste heat is expected to cause areas of evaporation and condensation in the unsaturated zone, especially during the first few hundred years when it is greatest (e.g., waste package temperature of approximately 170 °C [338 °F). The effects of this temperature change on drift seepage and relative humidity are important for estimating the effects of seepage water chemistry and deliquescent salt formation on corrosion rates of the drip shields or waste packages. (See also Section 4.3.3.) Generally, these effects are evaluated in performance assessments by considering different water chemistries and deliquescent salt formations in conjunction with corrosion, rather than explicitly representing the spatial and temporal variation in seepage and water chemistries.

Hydrologic Properties of the Unsaturated Zone: Medium Significance to Waste Isolation

For unsaturated zone flow paths that occur mainly within fractured welded or zeolitized tuff units, where matrix conductivities can be significantly lower than the percolation rate, the unretarded radionuclide traveltimes from the repository horizon to the water table are on the order of a few tens of years, because water flows primarily in fractures. Longer unsaturated zone traveltimes, on the order of several hundreds of years, are estimated for areas beneath the repository where the Calico Hills nonwelded vitric unit is present. The longer traveltimes in the Calico Hills nonwelded vitric unit are attributed to its relatively large matrix conductivity such that water tends to flow in the matrix rather than the fractures. The areal extent and thickness of the Calico Hills nonwelded vitric unit are considered to be moderately important aspects of unsaturated zone flow and transport.

Discussion

The Calico Hills nonwelded vitric unit is characterized by a relatively large matrix hydraulic conductivity; thus, for the range of anticipated percolation rates, the water flow in this unit is expected to remain in the matrix (i.e., no fracture flow) and be slow. Currently, the NRC performance assessment estimates that approximately half of the repository footprint will be underlain by sufficient thickness of the Calico Hills nonwelded vitric unit to have a significant effect on performance. If the thickness were to increase over a significantly larger portion of the footprint (e.g., 90 percent or greater), the unsaturated zone below the potential repository would have an ever increasing effect on performance. For example, Winterle, et al. (1999, Figure 2-2) evaluated the effects of Calico Hills nonwelded vitric unit extent and thickness using the TPA Version 3.2 code. The original basecase model for the TPA Version 3.2 code represented the Calico Hills nonwelded vitric unit beneath only two of seven potential repository subareas. Winterle, et al. (1999) stated that available borehole data suggest the presence of at least thin lenses of nonwelded vitric layers {as thin as 2 m [6.6 ft]} underneath all potential repository subareas. The Winterle, et al. (1999) analysis with the TPA Version 3.2 code indicated that consideration of Calico Hills nonwelded vitric unit layers under all subareas resulted in a reduction in the 10,000-year peak dose by a factor of about four.

Additionally, Figure 4-28 depicts unretarded radionuclide traveltimes from TPA Version 4.1 code analyses that fall into two distinct categories. The first category reflects flow paths with rather short unsaturated zone traveltimes (tens of years) and is representative of portions of the repository where the Calico Hills nonwelded vitric unit is not present beneath the repository (Figure 4-29). The second category represents much longer traveltimes (on the order of several hundreds of years) and is representative of areas beneath the potential repository primarily where the Calico Hills nonwelded vitric unit is present (Mohanty, et al., 2002, Section 3.3.5). If the unretarded traveltime is 500 years or longer, and the retardation factor is at least 20, radionuclides will not reach the water table within the regulatory period of 10,000 years. Current information indicates that a significant fraction of the inventory of the potential repository has retardation factors greater than 20. (See Section 4.3.7.) Current information indicates that approximately half the potential repository footprint is underlain by a sufficient thickness of the Calico Hills nonwelded vitric unit to have a significant effect on unsaturated zone unretarded radionuclide traveltimes. The DOE total system performance assessment includes a similar areal and thickness distribution of the Calico Hills nonwelded vitric unit, as is modeled in total TPA Version 4.1. The DOE sensitivity studies of unsaturated zone transport times, presented at the radionuclide transport technical exchange held in December 2000, also indicate that the Calico Hills nonwelded vitric unit is important for longer traveltimes.

Uncertainties

The thickness and areal extent of the Calico Hills nonwelded vitric unit directly below the potential repository are difficult to estimate precisely because there is a limited number of exploratory boreholes within the potential repository footprint. However, previous analyses have assessed the effect of this uncertainty (Winterle, et al., 1999).

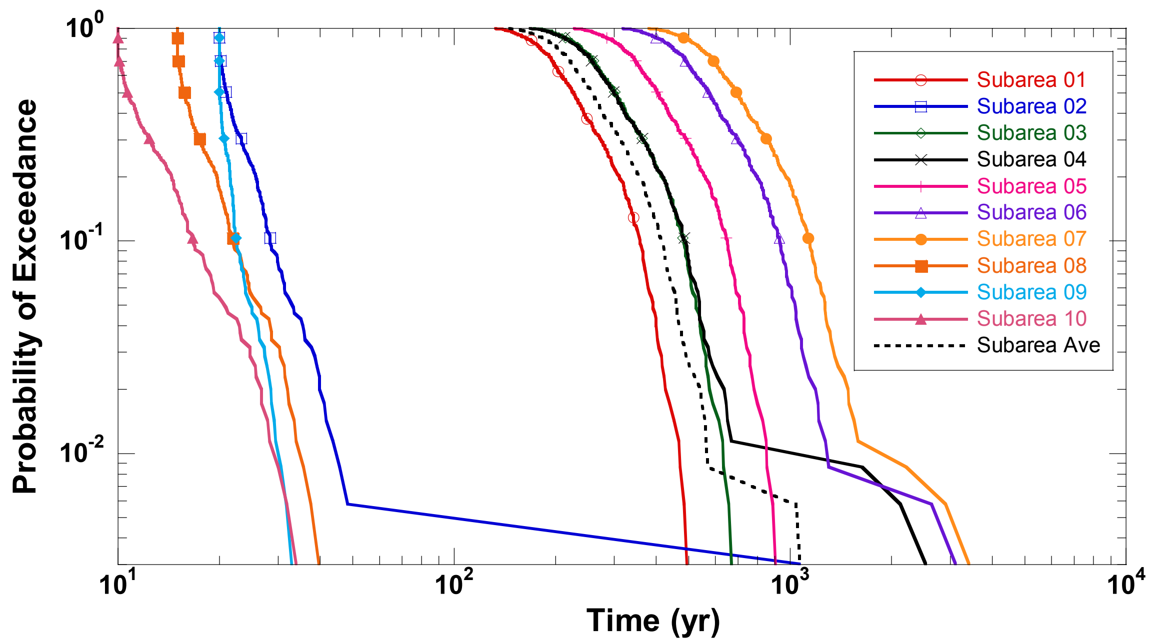


Figure 4-28. Complementary Cumulative Distribution Function of Unsaturated Zone Unretarded Radionuclide Traveltimes for Each of the 10 Repository Subareas and the Average of All 10 Areas (Based on 350 Realizations) (Mohanty, et al., 2002, Figure 3-30)

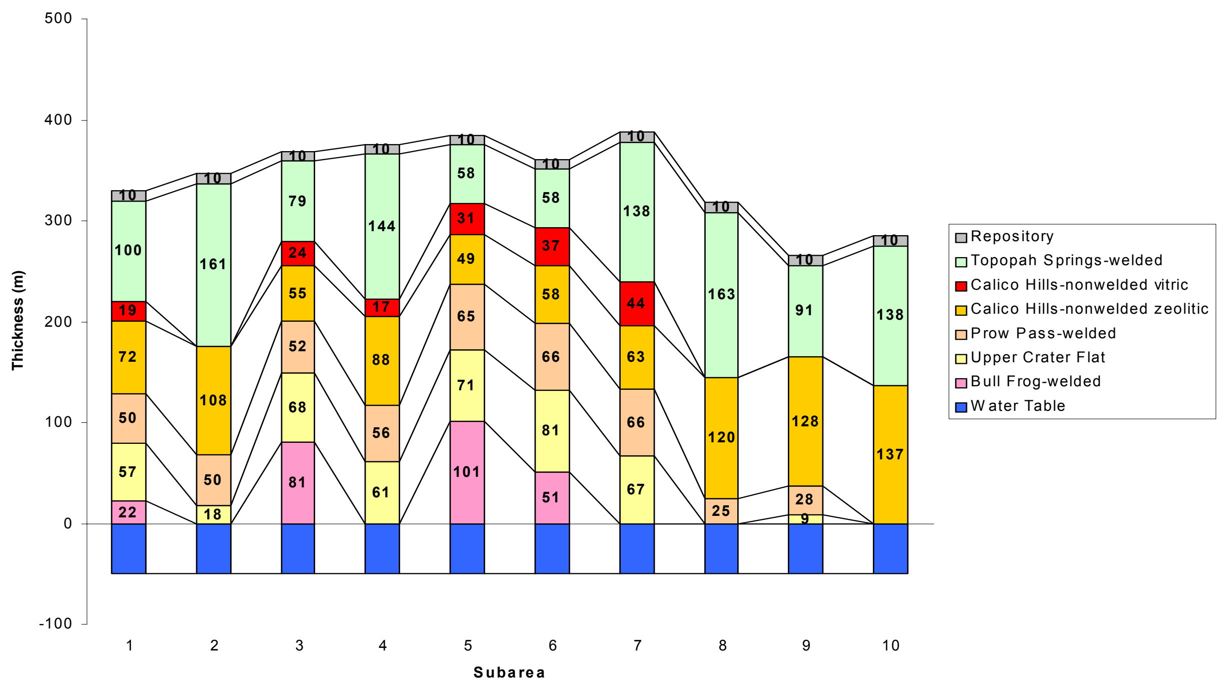


Figure 4-29. Depiction of the Stratigraphic Thicknesses Below Each of the 10 Repository Subareas (Mohanty, et al., 2002, Figure 3-9)

The flow paths in the unsaturated zone are also uncertain because of the potential for focusing of flow into fingers of flow rather than uniform flow or horizontal diversion of flow. It is anticipated that perturbations from focused flow will not have a significant potential for increasing consequences. For example, horizontal diversion of flow around low conductivity increases the flow path in a higher-conductivity zone, where there will be greater potential for matrix flow.

Values for the matrix conductivity of the unsaturated zone tuff units are important when the matrix conductivity is sufficiently large that a significant fraction of the percolation can be expected to flow in the matrix (e.g., conductivities at least 50 percent of the percolation rates). Representation of the uncertainty and variability in matrix conductivity in the range of the anticipated percolation rates {e.g., 10 mm/yr [0.4 in/yr]} is an important aspect of the unsaturated zone performance.

Transient Percolation: Low Significance to Waste Isolation

Episodic or transient percolation through the unsaturated zone below the root zone caused by short-term variation in precipitation does not significantly affect the spatial nor temporal variability of seepage into the drifts. After a precipitation event, infiltrating water moves in pulses vertically through the fractured rock unit and into the underlying rock units, where the pulses are variably damped in the Paintbrush tuff nonwelded unit into more steady vertical flow.

Discussion

Rainfall at the Yucca Mountain site is highly episodic, generally occurring over short periods of time. A small amount of the annual rainfall is estimated to contribute to net infiltration, whereas the bulk of the rainfall at Yucca Mountain is lost to evapotranspiration and runoff. Current estimates suggest, on average, approximately 5 percent of the rainfall contributes to infiltration (Figure 4-30). Although the infiltration near the surface is expected to be episodic, the pulses of infiltration are expected to be dampened as the infiltration moves deep (e.g., many tens of meters) below the surface. Although the rate may change from year to year, it is modeled as constant within any given year. As shown in Figure 4-30, the net infiltration (assumed to be the same as seepage in this figure) does not vary significantly despite larger changes in the precipitation rate. This is especially true for the initial 10,000 years, because infiltration at later years is influenced by cooler temperatures associated with a glacial period.

Uncertainties

Estimates of future short-, intermediate-, and long-term variations in precipitation are uncertain. Both NRC and DOE performance assessment models currently account for effects of short-term weather patterns and long-term climate changes. The effect of short-term variations are incorporated using 10-year records of hourly meteorological data, in process-level models, to support the total system performance assessment abstraction. Although the episodic nature of rainfall has an effect on the net infiltration, transient percolation is not expected to have a significant effect on seepage in the potential repository drifts, because of damping of flow variations in geologic units above the repository. The effects of long-term climate variations are addressed by including precipitation and temperature shifts, based on historical information on climate change, in performance assessments.